Novoptel

Stokes parameter logging
with polarimeter PM1000

Infoshare: State of polarization based sensing on optical fiber
12.02.2026

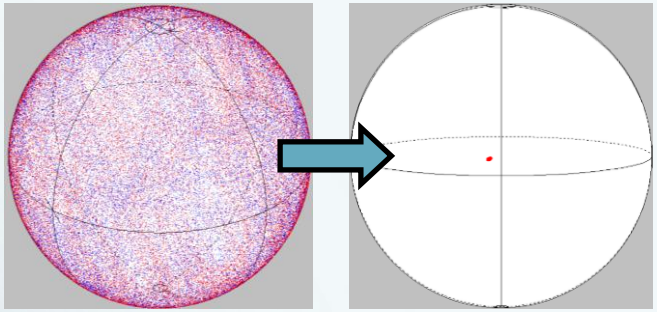
Benjamin Koch, Reinhold Noé

Company Overview

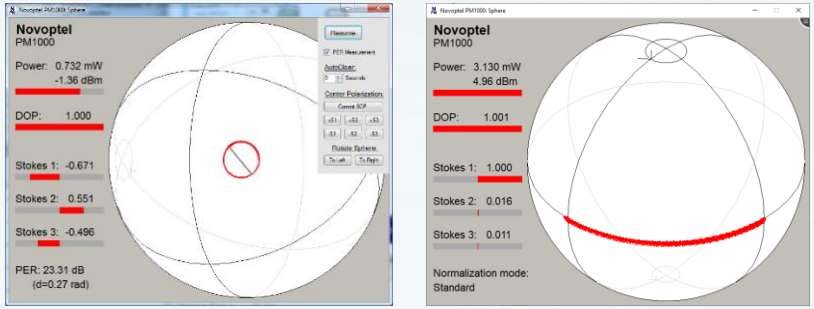
Novoptel

- Founded in 2010, spin-off from University of Paderborn
- Located in Paderborn, Germany
- Main Products:

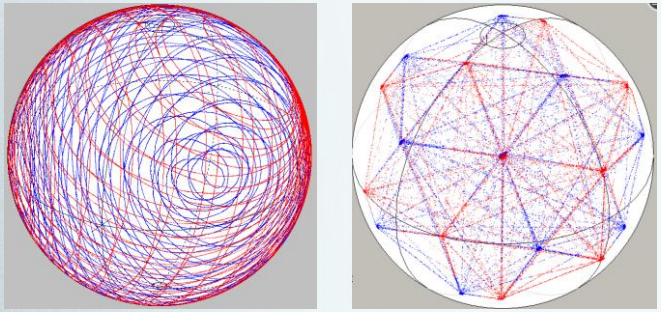
Polarization Controller/Demultiplexer EPC1000: 100 krad/s

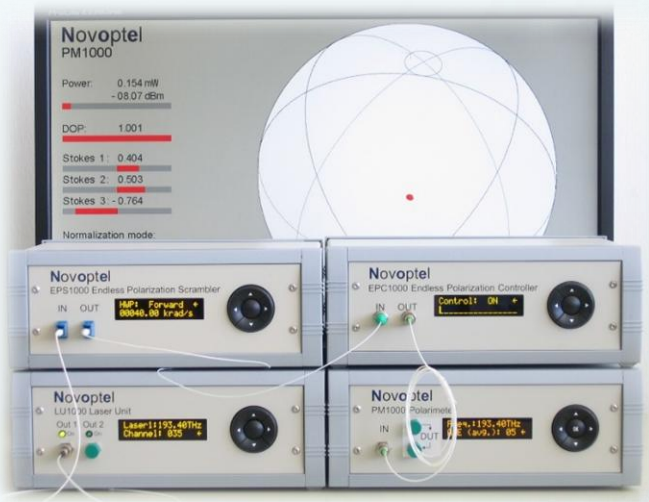


Polarimeter PM1000: 100 MS/s, 128 MS memory



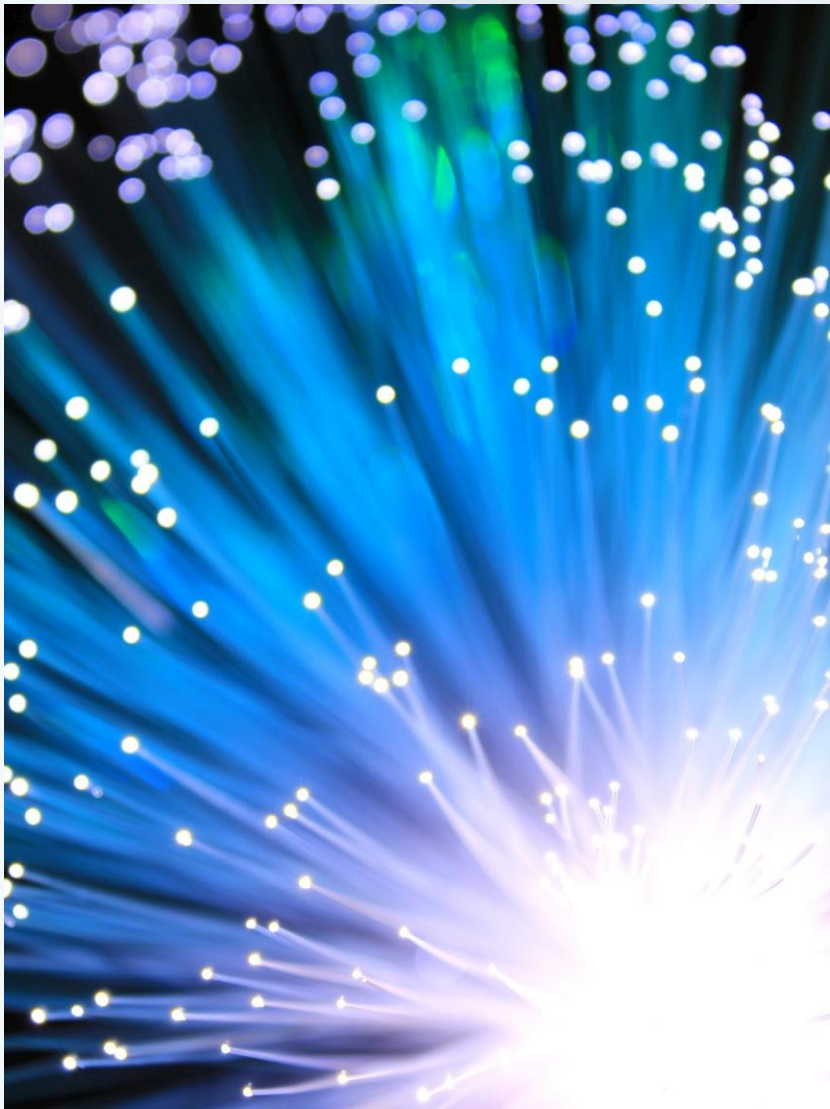
Polarization Scrambler/Depolarizer EPS1000: 20…80 Mrad/s





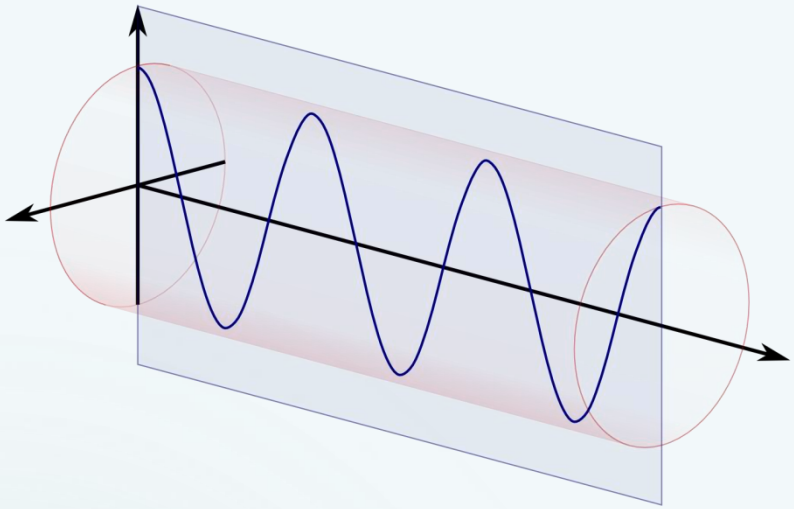
Outline

- Definition of polarization
- Poincaré sphere, Stokes vectors
- SOP measuring principle
- Overview of polarimeter PM1000
- Graphical User Interface (GUI)
- Examples of Event Recording
- Examples of Continuous Recording
  - Text / Binary Files
  - Evaluation



Definition of Polarization

Novoptel

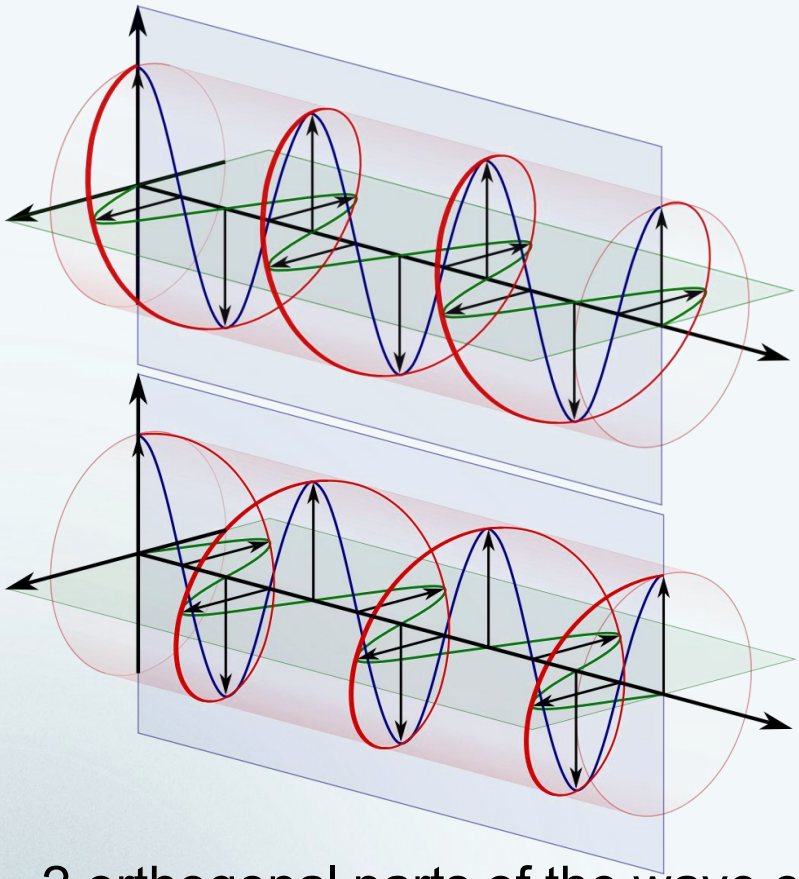


- Light is an electromagnetic (transverse) wave
- During transmission, an electrical and a magnetical field oscillates perpendicular to the transmission direction
- The **State of Polarization (SOP)** defines the oscillation direction of the electrical field, e.g. „vertical polarization“

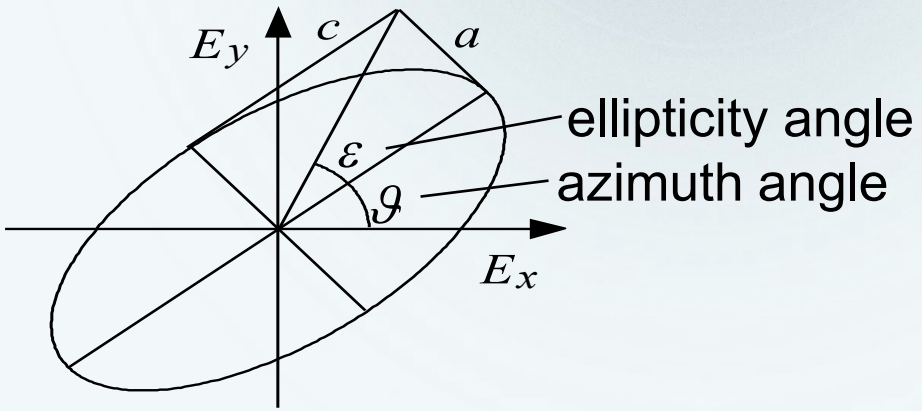
Figure: Wikipedia

Definition of Polarization

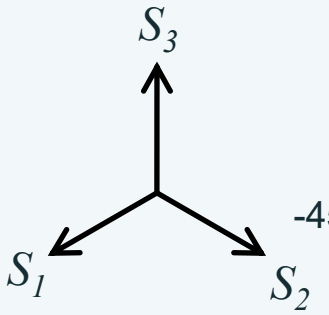
Novoptel

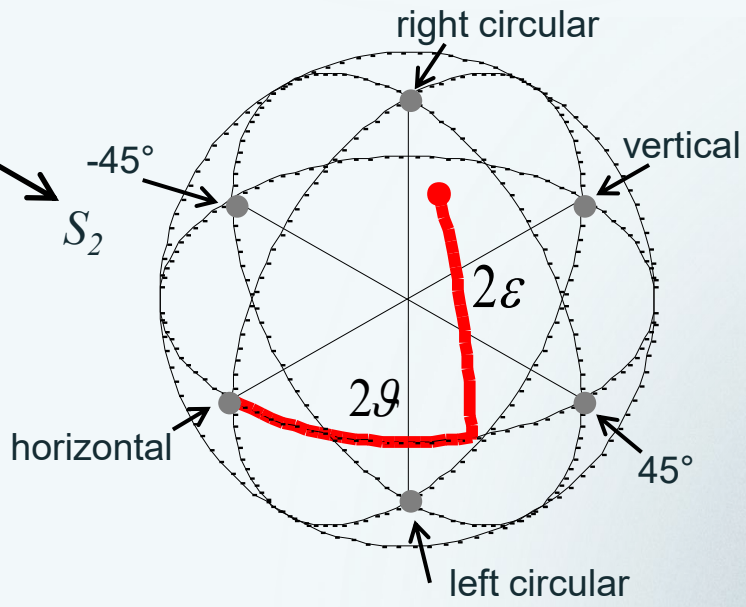


Polarization ellipse



Poincaré sphere





- 2 orthogonal parts of the wave can superimpose with different phases
- Every SOP can be displayed as a **polarization ellipse**.
- The double of both ellipticity angle and azimuth angle span the **Poincaré sphere**.

Figure: Wikipedia

Stokes Vectors

Novoptel

- Normalized Stokes vector with 3 parameters and length 1:

$$\vec{S} = \begin{pmatrix} S_1 \\ S_2 \\ S_3 \end{pmatrix} = \begin{pmatrix} cos2\epsilon \cdot cos2\vartheta \\ cos2\epsilon \cdot sin2\vartheta \\ sin2\epsilon \end{pmatrix}$$

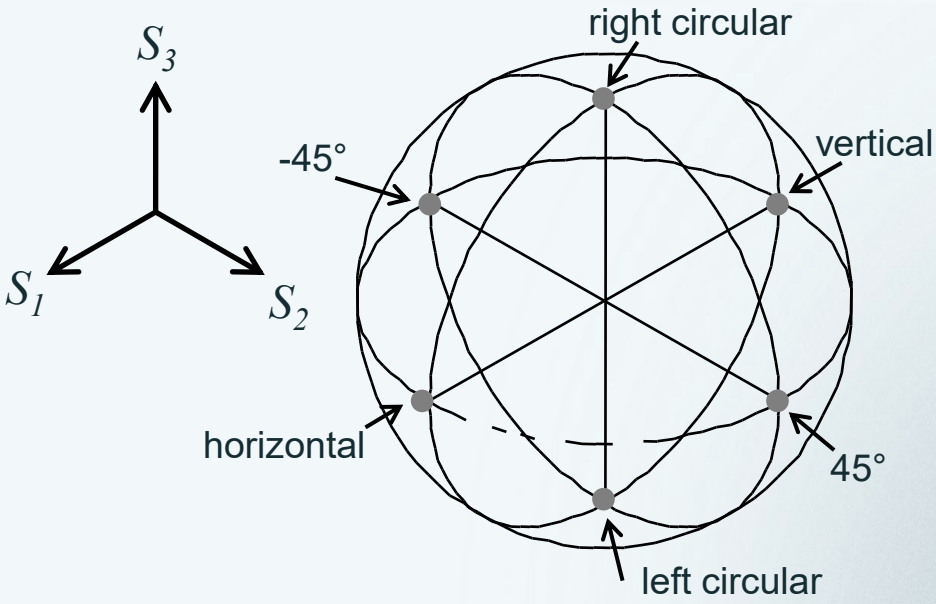
- Fundamental polarizations:

horizontal: $\begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix}$ vertical: $\begin{pmatrix} -1 \\ 0 \\ 0 \end{pmatrix}$

+45°: $\begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix}$ -45°: $\begin{pmatrix} 0 \\ -1 \\ 0 \end{pmatrix}$

right circular: $\begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix}$ left circular: $\begin{pmatrix} 0 \\ 0 \\ -1 \end{pmatrix}$

Poincaré sphere



Stokes Vectors

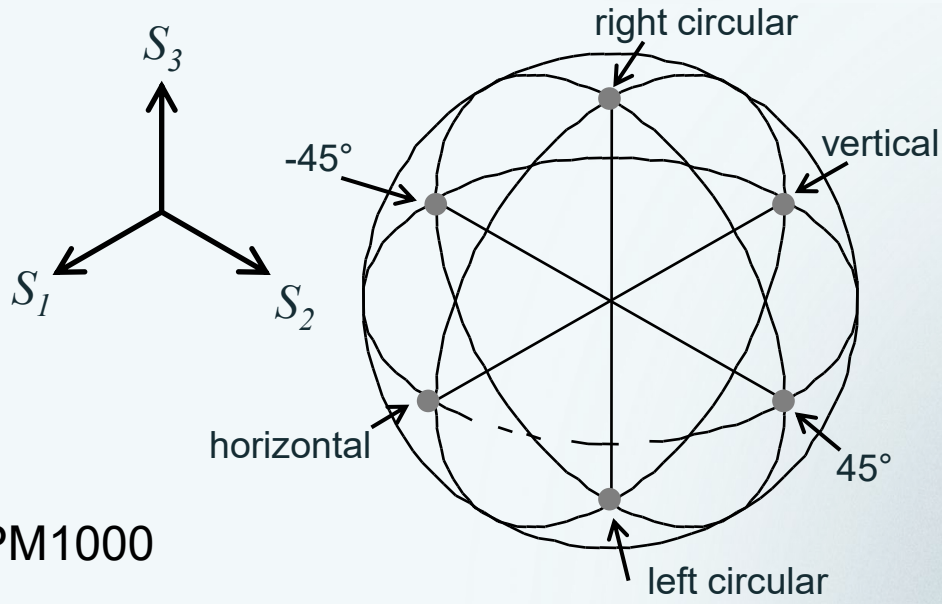
Novoptel

- General Stokes vector with 4 parameters:

$$\vec{S}' = \begin{pmatrix} S_0' \\ S_1' \\ S_2' \\ S_3' \end{pmatrix} = \begin{pmatrix} \overline{\left|\vec{E}\right|^2} \\ \overline{\left|\vec{E}\right|^2 \cdot cos2\epsilon \cdot cos2\vartheta} \\ \overline{\left|\vec{E}\right|^2 \cdot cos2\epsilon \cdot sin2\vartheta} \\ \overline{\left|\vec{E}\right|^2 \cdot sin2\epsilon} \end{pmatrix}$$

$$\text{DOP} = \frac{\sqrt{S_1'^2 + S_2'^2 + S_3'^2}}{S'_0}$$

Poincaré sphere



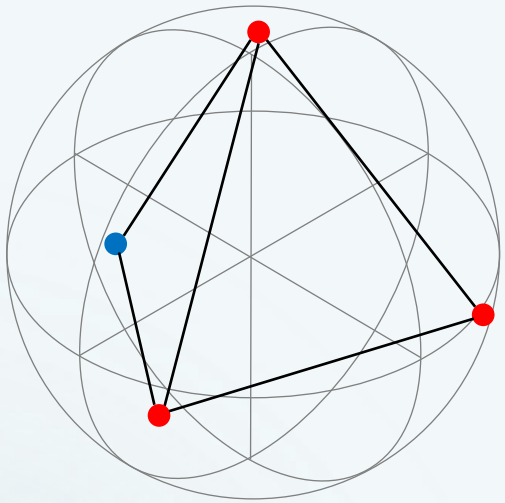
- 4 degrees of freedom:

  1 (power) + 2 (SOP) + 1 (DOP)

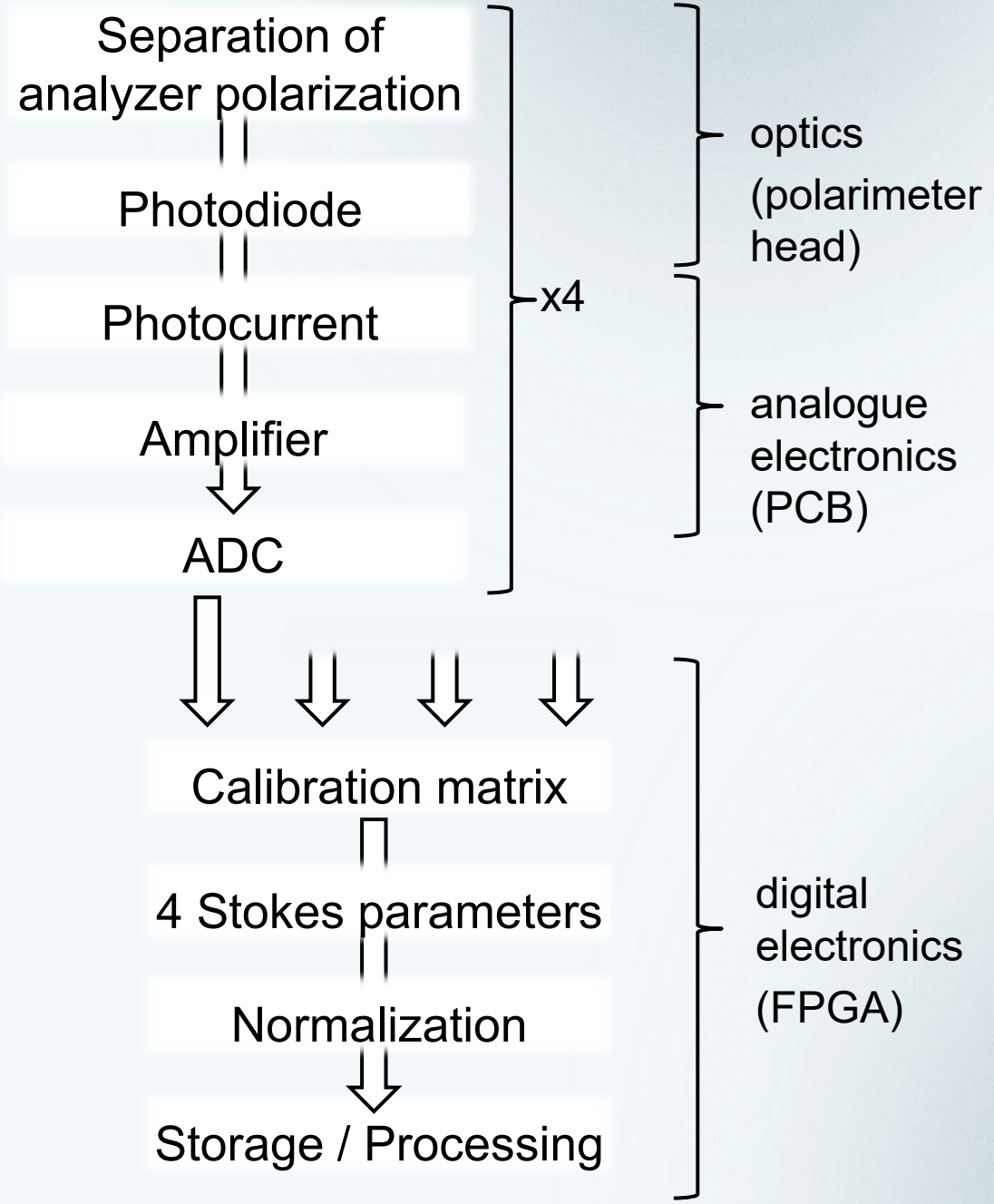
- Different normalization types exist in PM1000

SOP Measuring Principle

Novoptel



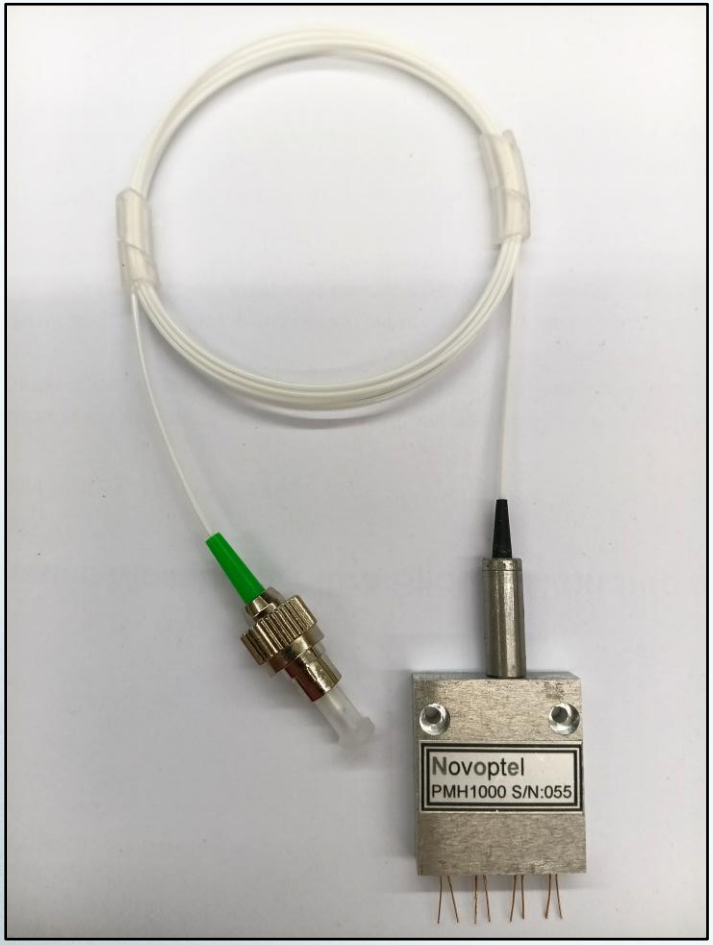
- Measure power in 4 fixed analyzer polarizations.
- Ideal case: 4 corners of a tetrahedron
- Again 4 degrees of freedom



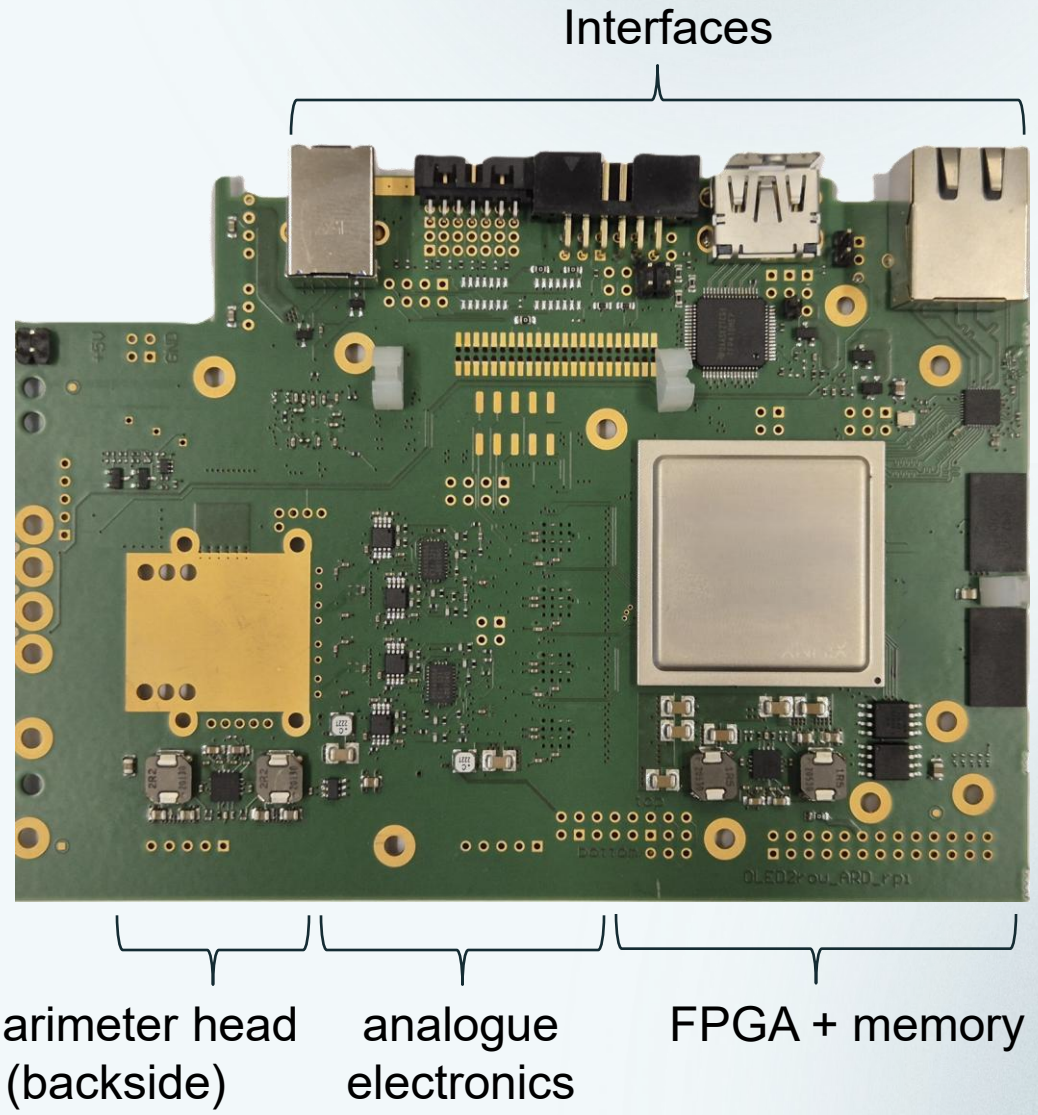
PM1000 Hardware

Novoptel

- Polarimeter head:



- PCB / module:



PM1000 Overview

- Desktop instrument (also: Rackmount or PCB/module)
- Sampling frequency: 100 MHz
  - adjustable averaging
- Internal memory: 8 Gbit (128 MSamples)
- Interfaces: HDMI, USB 3.0, Gbit Ethernet
- Clock synchronization to 1PPS real time source
- Software: GUI (Windows), Matlab, Python (Windows/Linux)

Net data rate ~ 400 Mbit/s (6 MS/s)

Recording Types

Novoptel

memory block
(2^{ME} samples, 10<ME<27)

8 Gbit memory (128 MSamples)

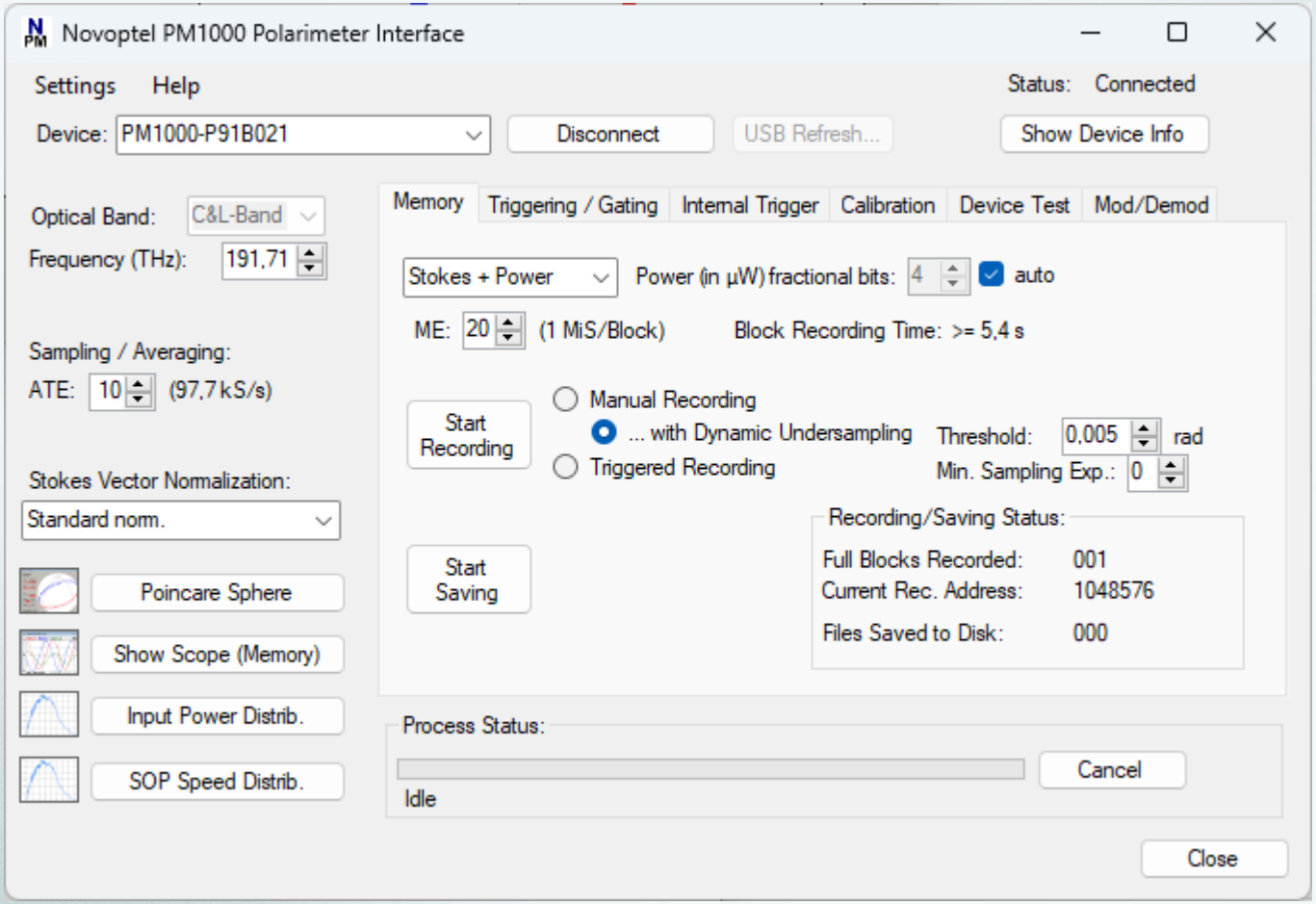
- Data Stream: Continuous transfer of SOP data at adjustable sampling rate
- Manual Recording:

  Records 1 memory block and stops. Block size is defined by *Memory Exponent* (ME). Sampling time is defined by *Averaging Time Exponent* (ATE): $t_S=2^{ATE}\cdot 10$ ns, $f_S=100$ MHz$/2^{ATE}$
- Triggered Recording:

  Uses memory blocks as ringbuffers for continuous recording. Upon a defined trigger event, it continues recording in the current block for the amount of post-trigger samples. After that, it continues in the next block.
- (Endless) Dynamic Undersampling:

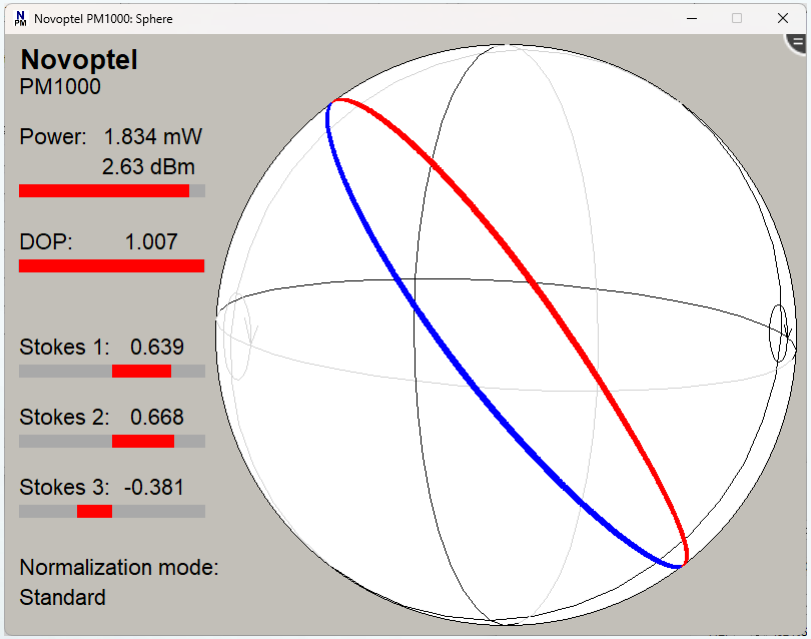
  A sample is only recorded if it differs by the previous recorded sample by more than a defined threshold. Once a block is completed, the GUI/script can transfer it. The GUI/script marks transferred blocks so they can be overwritten with new data by PM1000.

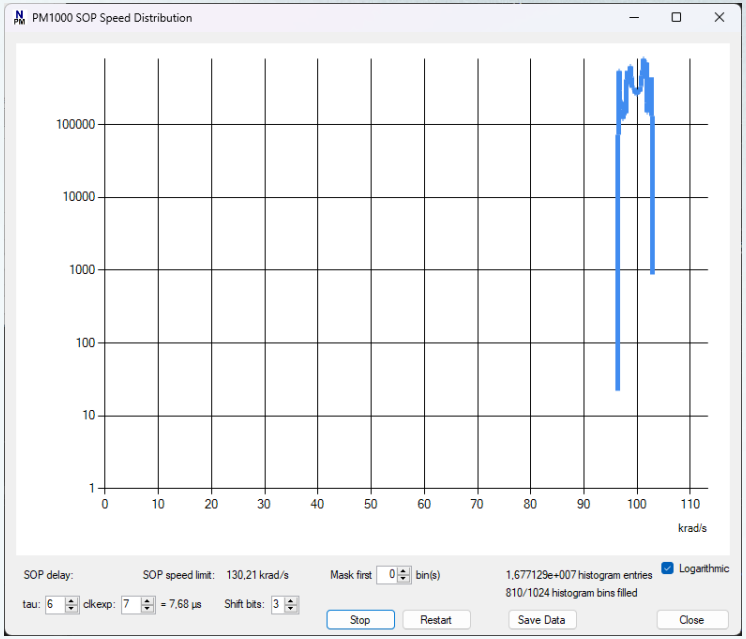
PM1000 GUI Overview

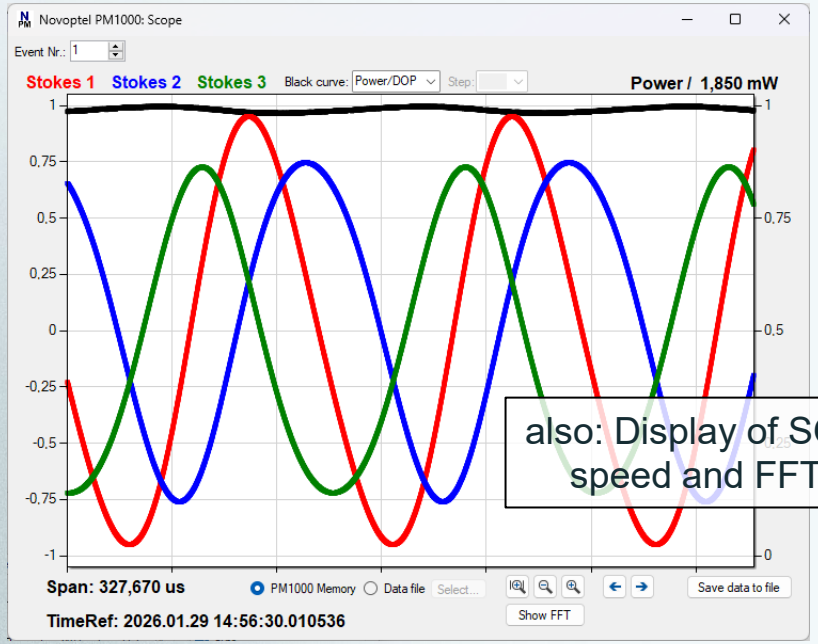


PM1000 GUI Overview

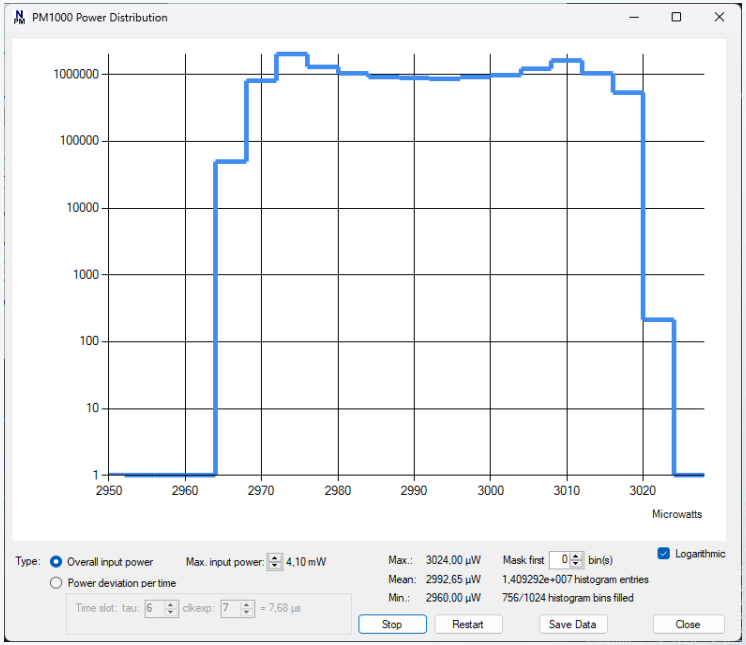
Novoptel







also: Display of SOP speed and FFT

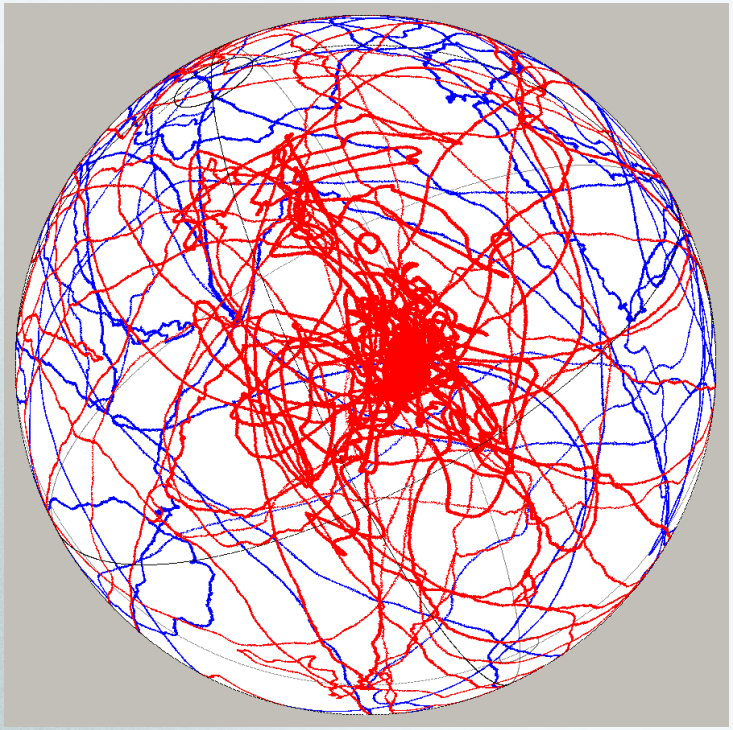


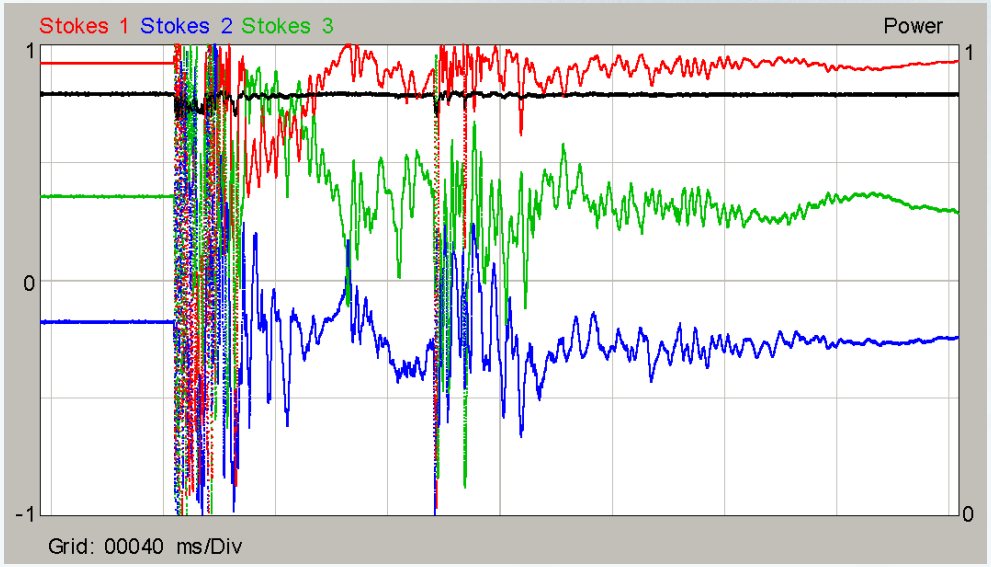
Event Recording

Novoptel

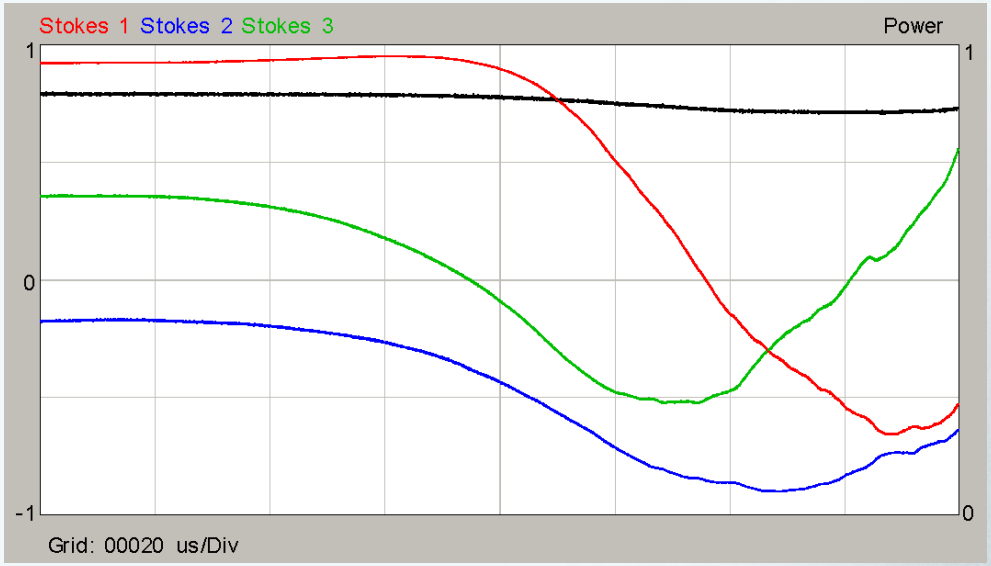
A hammer (0.3 kg) was dropped from a height of 2 cm on a fiber cassette DCM-40.

The internal trigger was set to >0.1 rad polarization change in 10.24 μs, so roughly 10 krad/s speed.





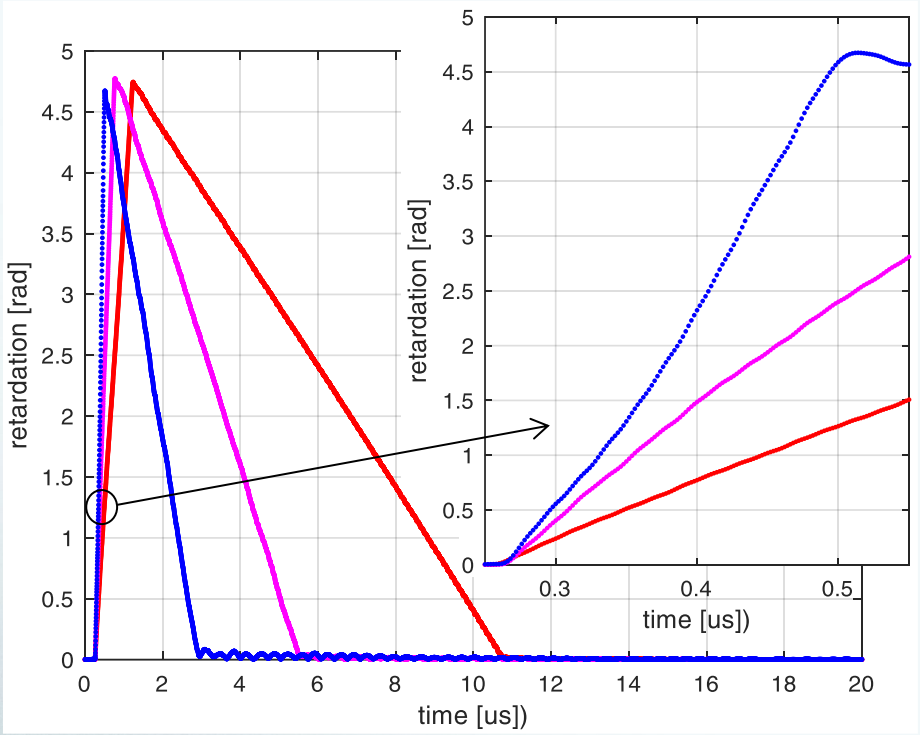
Start of event, zoomed by a factor of 2000:



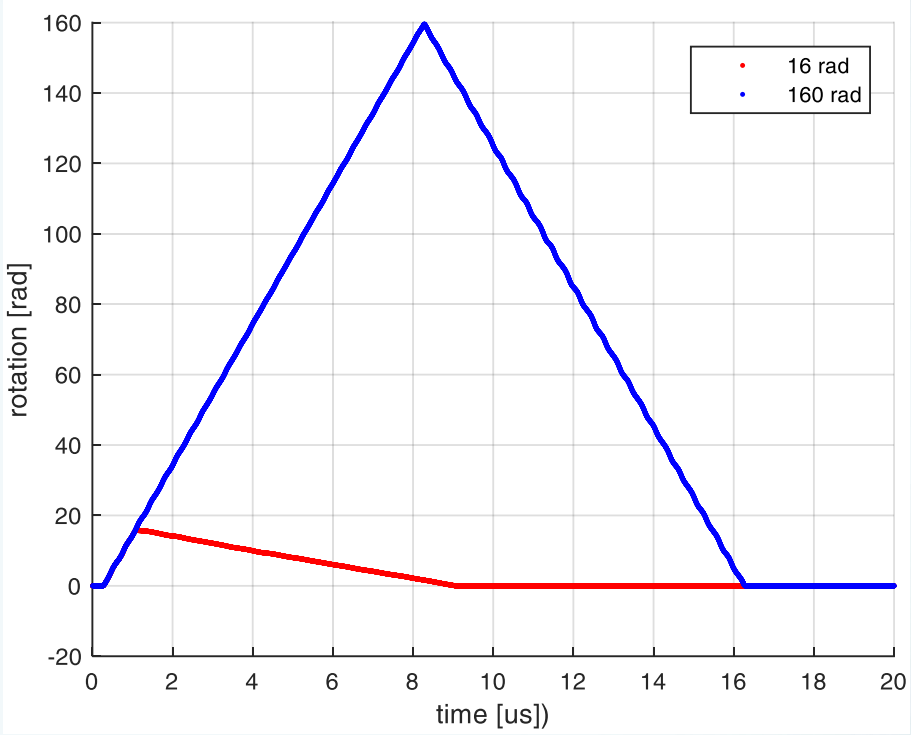
Event Recording

Novoptel

Detection of emulated lightning strikes



blue: 20 Mrad/s for 240 ns, -2 Mrad/s for 2400 ns
magenta:10 Mrad/s for 480 ns, -1 Mrad/s for 4800 ns
red: 5 Mrad/s for 960 ns, -0.5 Mrad/s for 9600 ns



blue: 20 Mrad/s for 8 µs, -20 Mrad/s for 8 µs
red: 20 Mrad/s for 0.8 µs, -2 Mrad/s for 8 µs

R. Noé, B. Koch, V. Mirvoda, *Emulation of polarization fluctuations in glass fibers caused by lightning strikes*, 19. Fachtagung "Photonische Netze", 11-12 June 2018, Leipzig, Germany, ITG-Fachbericht 279, pp. 96-99, ISBN 978-3-8007-4684-2

Continuous Recording: Text Files

Novoptel

SOP logging with dynamic undersampling

1 M Samples + Timestamps:

57.8 MB (text files)

logtest_20260122_131343.txt

```
# Timestamp_Start_Python = 1769084018.504965067
# Timestamp_Start_Win    = '2026-01-22 13:13:38'
0.15347105,  1.88056,   -0.82489,   0.34732,   0.44623
0.15347617,  1.88031,   -0.82611,   0.34802,   0.44434
0.15348129,  1.88050,   -0.82703,   0.34811,   0.44223
0.15348641,  1.88112,   -0.82782,   0.34863,   0.44037
0.15349153,  1.88088,   -0.82861,   0.34891,   0.43848
0.15349665,  1.88062,   -0.82916,   0.34918,   0.43661
0.15350177,  1.88081,   -0.82935,   0.35150,   0.43552
0.15350689,  1.88094,   -0.82968,   0.35159,   0.43393
0.15351201,  1.88081,   -0.83121,   0.35123,   0.43176
0.15351713,  1.88094,   -0.83176,   0.35233,   0.42963
0.15352225,  1.88119,   -0.83282,   0.35257,   0.42722
0.15352737,  1.88106,   -0.83362,   0.35339,   0.42535
0.15353249,  1.88138,   -0.83316,   0.35507,   0.42432
0.15353761,  1.88100,   -0.83414,   0.35553,   0.42267
0.15354273,  1.88088,   -0.83469,   0.35632,   0.42081
0.15354785,  1.88031,   -0.83514,   0.35706,   0.41968
0.15355297,  1.87925,   -0.83566,   0.35678,   0.41782
0.15355809,  1.87994,   -0.83630,   0.35687,   0.41650
0.15356321,  1.88006,   -0.83682,   0.35901,   0.41412
0.15356833,  1.88006,   -0.83737,   0.36035,   0.41171
0.15357345,  1.88031,   -0.83798,   0.36041,   0.40988
0.15357857,  1.88069,   -0.83826,   0.36148,   0.40826
0.15358369,  1.88163,   -0.83878,   0.36176,   0.40692
0.15358881,  1.88231,   -0.83984,   0.36310,   0.40427
0.15359393,  1.88200,   -0.84030,   0.36435,   0.40262
0.15359905,  1.88169,   -0.84058,   0.36462,   0.40100
0.15360417,  1.88175,   -0.84164,   0.36542,   0.39859
0.15360929,  1.88106,   -0.84164,   0.36621,   0.39752
0.15361441,  1.88031,   -0.84235,   0.36694,   0.39560
0.15361953,  1.88031,   -0.84290,   0.36777,   0.39371
0.15362465,  1.88044,   -0.84344,   0.36801,   0.39212
0.15362977,  1.88031,   -0.84369,   0.36884,   0.39023
0.15363489,  1.88094,   -0.84433,   0.36996,   0.38815
0.15364001,  1.88044,   -0.84485,   0.37024,   0.38629
0.15364513,  1.88000,   -0.84531,   0.37149,   0.38434
```

Continuous Recording: Binary Files

Novoptel

SOP logging with dynamic undersampling

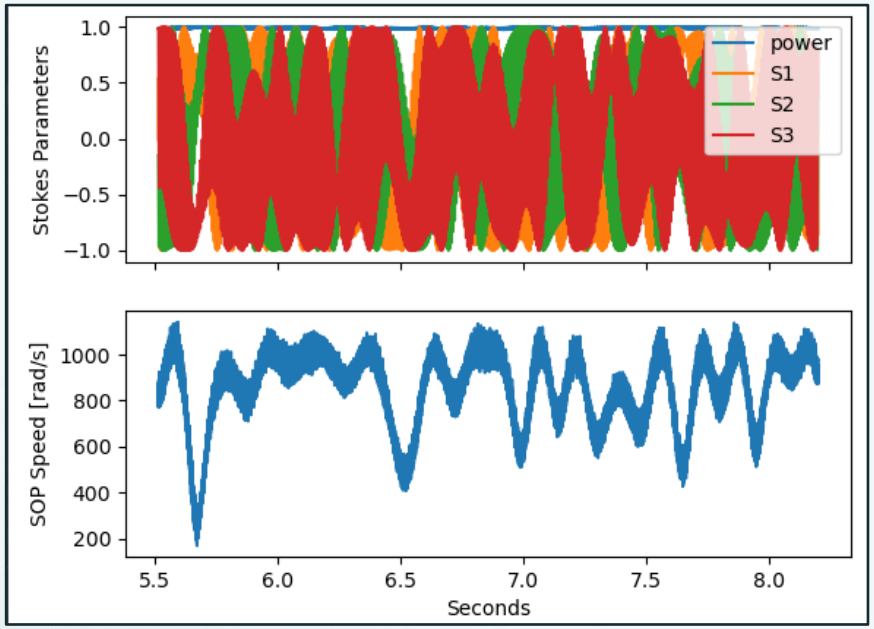
1 M Samples + Timestamps:
16.4 MB (binary files)

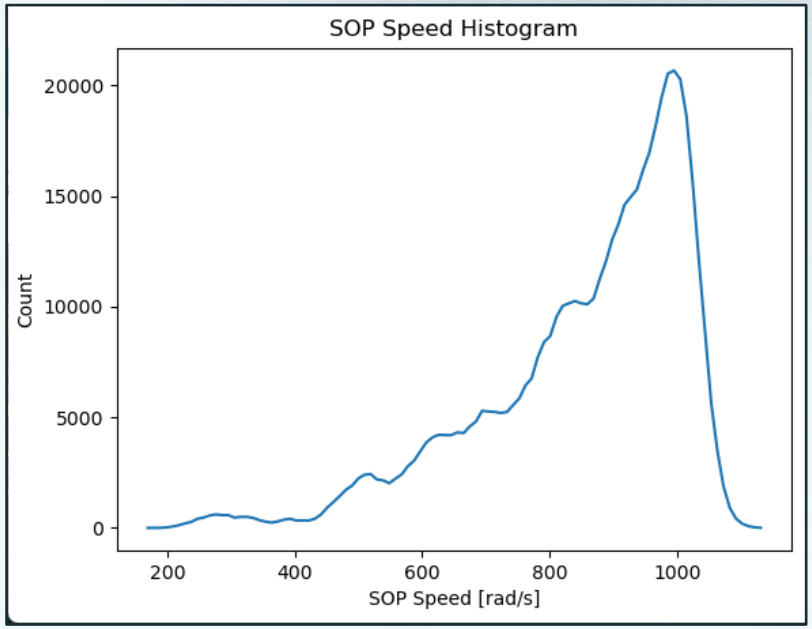
logtest_20260122_131639.bin

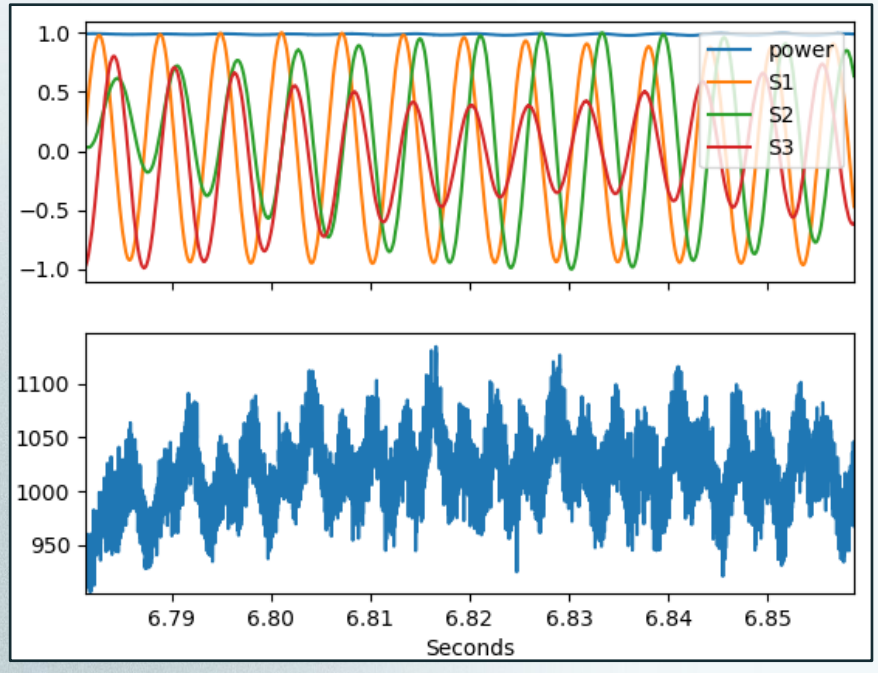
Offset (h)	00	01	02	03	04	05	06	07	08	09	0A	0B	0C	0D	0E	0F	Dekodierter Text
00000000	23	20	54	69	6D	65	73	74	61	6D	70	5F	53	74	61	72	# Timestamp_Star
00000010	74	5F	50	79	74	68	6F	6E	20	3D	20	31	37	36	39	30	t_Python = 17690
00000020	38	34	31	38	39	2E	35	30	32	31	33	35	30	33	38	0A	84189.502135038.
00000030	23	20	54	69	6D	65	73	74	61	6D	70	5F	53	74	61	72	# Timestamp_Star
00000040	74	5F	57	69	6E	20	3D	20	27	32	30	32	36	2D	30	31	t_Win = '2026-01
00000050	2D	32	32	20	31	33	3A	31	36	3A	32	39	27	0A	23	20	-22 13:16:29'.#
00000060	50	6F	77	45	78	70	20	3D	20	34	0A	00	00	00	00	00	PowExp = 4.....
00000070	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
00000080	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
00000090	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
000000A0	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
000000B0	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
000000C0	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
000000D0	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
000000E0	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
000000F0	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
00000100	40	92	CF	48	01	00	00	00	8E	7E	CC	EC	C2	FE	D0	74	@'ÏH....Ž~ÌìÂþÐt
00000110	40	A6	CF	48	01	00	00	00	96	7E	A9	EC	58	FF	CE	74	@¦ÏH....–~©ìXÿÎt
00000120	40	BA	CF	48	01	00	00	00	7C	7E	5C	EC	B9	FF	D1	74	@ºÏH....|~\ì¹ÿÑt
00000130	40	CE	CF	48	01	00	00	00	7C	7E	FF	EB	2C	00	C9	74	@ÎÏH....|~ÿë,.Ét
00000140	40	E2	CF	48	01	00	00	00	73	7E	C1	EB	CA	00	C3	74	@âÏH....s~ÁëÊ.Ãt
00000150	40	F6	CF	48	01	00	00	00	61	7E	6C	EB	2B	01	C1	74	@öÏH....a~lë+.Át
00000160	40	0A	D0	48	01	00	00	00	47	7E	25	EB	B8	01	C2	74	@.ÐH....G~%ë¸.Ât
00000170	40	1E	D0	48	01	00	00	00	50	7E	11	EB	34	02	C2	74	@.ÐH....P~.ë4.Ât
00000180	40	32	D0	48	01	00	00	00	47	7E	DC	EA	A6	02	C5	74	@2ÐH....G~Üê¦.Åt
00000190	40	46	D0	48	01	00	00	00	35	7E	96	EA	22	03	CC	74	@FÐH....5~–ê".Ìt
000001A0	40	5A	D0	48	01	00	00	00	2C	7E	61	EA	A6	03	D0	74	@ZÐH....,~aê¦.Ðt
000001B0	40	6E	D0	48	01	00	00	00	12	7E	1A	EA	21	04	CE	74	@nÐH.....~.ê!.Ît
000001C0	40	82	D0	48	01	00	00	00	01	7E	D7	E9	93	04	D2	74	@‚ÐH.....~×é".Òt
000001D0	40	96	D0	48	01	00	00	00	E6	7D	76	E9	06	05	C4	74	@–ÐH....æ}vé..Ät
000001E0	40	AA	D0	48	01	00	00	00	D4	7D	23	E9	82	05	BC	74	@ªÐH....Ô}#é‚.¼t
000001F0	40	BE	D0	48	01	00	00	00	D4	7D	1B	E9	EB	05	B8	74	@¾ÐH....Ô}.éë.¸t
00000200	40	D2	D0	48	01	00	00	00	C3	7D	D4	E8	67	06	C1	74	@ÒÐH....Ã}Ôèg.Át
00000210	40	E6	D0	48	01	00	00	00	B1	7D	9F	E8	FD	06	C7	74	@æÐH....±}Ÿèý.Çt
00000220	40	FA	D0	48	01	00	00	00	9F	7D	6A	E8	6F	07	D4	74	@úÐH....Ÿ}jèo.Ôt
00000230	40	0E	D1	48	01	00	00	00	8D	7D	18	E8	EC	07	DF	74	@.ÑH.....}.èì.ßt

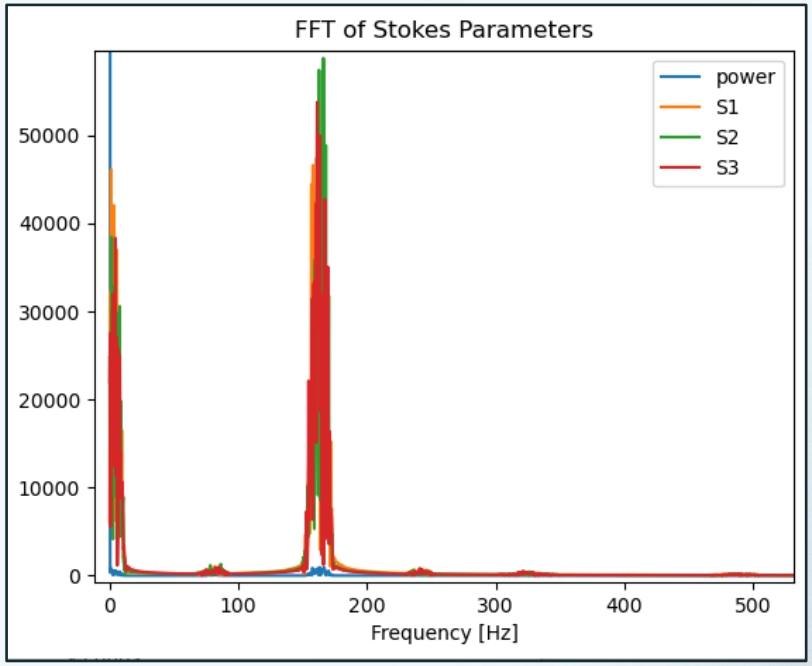
Continuous Recording: Evaluation (Python)

Novoptel









Future developments

- Data analysis inside PM1000 FPGA for
  - pre-evaluation, generation of trigger signals or
  - reduction of transferred data
- Analysis of polarization-multiplexed signals (appear depolarized, DOP=0)
- Display with Poincaré sphere at the front
- Standalone unit with large hard disk drive inside
- ?

Thank you!